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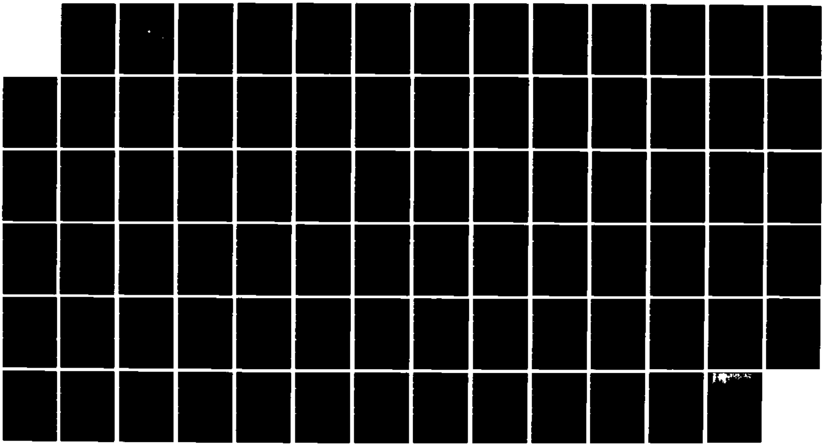

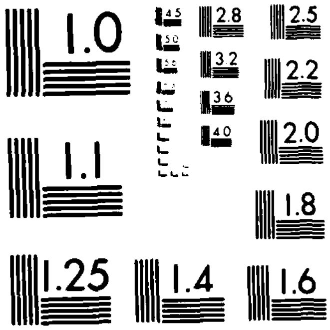
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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

UNIQUE CONSIDERATIONS IN THE DESIGN OF A COMMAND AND CONTROL DECISION SUPPORT SYSTEM

by

Candace Lee Conwell

June 1983

Thesis Advisor: Roger Weissinger-Baylon

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Unique Considerations in the Design of a Command and Control Decision Support System

by

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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

Decision Support Systems (DSS) have been identified as a solution to the military commander's needs for information filtering and analysis. Current literature on the theory and techniques of DSS design have been addressed to the decision-making processes of commercial applications. The lack of a comprehensive treatement of military command and control decision-making requirements may result in a number of command and control DSS which are not designed for the reliability and flexibility required in a context of ever-changing threats. This thesis is an initial attempt to identify some unique considerations for the design of a command and control decision support system and offers suggestions towards the development of flexible, reliable systems to serve commanders in both peacetime and combat operations.

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I. INTRODUCTION

The Navy has been using computers longer than any other organization. The Harvard Mark I and the ENIAC were providing data for ballistic studies in the late 1940's. Since then, the Navy has become dependent on computers for virtually all its essential activities from payroll to weapons control [Ref. 1: pp. 6-7]. While such extensive employment of computing capabilities has without doubt allowed the Navy to run a leaner, more capable operation, it has also resulted in the same "information overload" problem which has received so much publicity in the business press.

Managers and businessmen in the private sector have long complained that the so-called Management Information Systems, or MIS, have had little or no beneficial effect on managerial decision-making. Managers do not need more data; they need a way to filter data, to view it from different angles, to make projections, and to conduct variance and sensitivity analyses. The concept of Decision Support Systems (DSS), which was made possible in the late 1960's with the introduction of time sharing and remote terminals, provided the potential for managers to use information "instead of being buried under it" [Ref. 2: p. 33].

Most discussion of the use of DSS to support military decision-making is limited to proposals and suggestions. While several projects are underway to field prototype DSS, the actual capability to perform analyses on data is usually planned for later versions of the system. This is especially true for systems which will support such complex and difficult-to-define missions such as command and control.

Still, the need is there; commanders on ships and in the field are just as inundated with data as any other manager, if not considerably more so. DSS promises to help these commanders filter information, analyze data, compare alternatives and transmit commands, all from the same console.

The Soviets also see the need for command and control DSS. Fleet Admiral Gorshkov shares our Secretary of Defense's opinion that the status of a force's Command and Control elements will be an equally important determinant in war as that of the level of technology of weapons systems [Ref. 3: p. 7, Ref. 4: p. 241]. Gorshkov recently presented a paper in which he identifies the modeling and analytical capabilities of a Command and Control decision-supporting computer system as capabilities which will be essential to permit commanders to make decisions in an environment which will be distinguished by the "large spatial scope, accelerated tempo, and sharp variation in the situation...."

With a well-established need, and with the increasing recognition of the importance of Command and Control, it is not at all surprising that the concept of Command and Control DSS has already attracted much attention in the Navy. Unfortunately, current textbooks and actual DSS examples are strictly commercial applications for such purposes as financial and production management. Military planners or project managers who will be responsible for the design specifications of Command and Control DSS will find very little in the way of formal guidance.

The purpose of this research, then, is to consolidate what information available in the scattering of applicable articles in military journals with this author's knowledge of Navy command and control to provide a general outline of unique considerations in the design of a Command and Control DSS. It is hoped that this thesis will also serve to stimulate further interest and research towards more complete and formal textbooks or manuals on the subject.

II. A PLACE FOR DSS IN COMMAND AND CONTROL

Command and control has always been an important element in war, and in this age of nuclear weapons and the need for instant response, it has become even more important. Soviet Fleet Admiral Gorshkov emphasizes the role of command and control in warfare, "Disrupting enemy control of forces in a number of instances can produce no less an effect than their immediate defeat..." [Ref. 3: p. 9].

The current administration has recognized this critical role of command and control. In his Annual Report to the Congress for Fiscal Year 1984, Defense Secretary Weinberger emphasizes the dependence of force capability upon command and control systems [Ref. 4: p. 241]. Roughly $15 billion a year is now being invested in these systems, making command and control the fastest growing functional component of the U.S, defense budget [Ref. 5: p. 28].

A. TODAY'S COMMAND AND CONTROL SYSTEMS: THE CHALLENGE

As Secretary Weinberger states in the FY 1984 Report, "The variety and complexity of our C3I* systems presents us with an extremely challenging management task" [Ref, 4: p. 241]. Most of our command and control systems evolved

*"C3I" is the acronym for Command, Control, Communications, and Intelligence.

independently and are supported by a collection of equipment whose architectures are 15 to 30 years old, with low meantime between failure and high maintenance costs. Like many other military computer systems they involve software which is "non-portable, inflexible and largely unresponsive, expensive to develop and maintain, with little or no interoperability and few standards.." [Ref. 6: p. 26].]

The challenge today is to upgrade and integrate current command and control systems and to develop and acquire new systems which [Ref. 4: pp. 241-242]:

- provide a "proper mix" with weapons systems,
- can evolve with changing needs for information,
- are affordable,
- meet the requirements of the decisionmakers they will serve,
- are survivable in both lethal and electronic warfare,
- are interoperable, both among our own Services and with our allies, in joint and combined military operations,
- are consistent with long range plans developed jointly with the Defense Intelligence Agency and the JCS.

Obviously, such goals will not be achieved overnight. Command and control is a very complex mission. Robert B. Doane of the Air Force Systems Command's Electronic Systems Division states that before it will be possible to develop a satisfactory command and control architecture, it is first necessary to undertake "...a concerted effort to define, with a degree of stability, the top-level information needs

for all levels of command, ...from the 'local' (battle) commanders up through the JCS--a very difficult task" [Ref. 7: p. 182].

B. DIFFERENT CONCEPTS OF COMMAND AND CONTROL

Still others say that command and control defies precise definition, [Ref. 8: pp. 96] and that the "absence of a succinct statement of objectives" at the national level has resulted in command and control systems which have been driven instead by the push for technological sophistication. [Ref. 9: pp. 48-69].

There are indeed many different concepts of command and control. The JCS Pub 1 offers this definition:

> "The exercise of authority and direction by properly designated commanders over assigned forces in the accomplishment of his mission. Command and control functions are performed through an arrangement of equipment, communication, facilities and procedures in planning, directing and controlling forces and operations in the accomplishment of his mission" [Ref. 7: p. 182].

Another definition of command and control emphasizes the process of decision-making [Ref. 10: p. 15]:

> "..a process: or, more accurately, a set of related processes. It is, first, a process of getting information to decision makers. Second, it is a process of interaction between decision makers. Third, it is a process of implementing their decisions. All three of these vital processes are centered around decision makers: the task of command and control is to help them see more clearly what is happening, decide what to do about it and implement the necessary actions."

It is this latter definition which, in the opinion of this writer, will best support efforts to design integrated

command and control systems. Its emphasis on the decision maker is more promising in achieving Secretary Weinberger's goal of developing systems which will serve the information needs of the intended users. Its division of the process of command and control into the three 'subprocesses' of gathering information, interaction among decision-makers and implementing decisions highlights the importance of communications in command and control decision making. It also closely resembles Simon's paradigm of decision making* and thus allows inspection of current command and control systems as to how well they support each of the three stages of decision making.

C. *COMMAND AND CONTROL DECISION-MAKING*

The decision-making phases identified by Simon are the "intelligence" phase, the "design" phase and the "choice" phase. The decision-making process involves the iteration of these phases, where "intelligence" is the gathering of data, "design" is the manipulation and analysis of the data, and "choice" is the selection and implementation of a course of action.

The intelligence phase of decision-making in command and control, or the gathering of information is already well-supported by sophisticated sensors and communications

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*See Appendix, Section C.

technology. It is the design and choice phases, in which alternatives are evaluated and implemented, where current command and control systems provide little support for commanders. The Assistant Secretary of the Navy (Research, Engineering and Systems), John Paisley was quoted in SIGNAL Magazine [Ref. 11: p. 23]:

> "Our ability to collect, process and transport information at prodigious rates is great and continues to expand and already has exceeded our ability to assimilate and comprehend. The commander...has more information than he can use. The difficulty is that the information is not always in the right form or presentation and it may not be available 'in-time,' but without question, he has more than he can use."

Commanders must be provided some means for "assessment, aggregation and correlation of vasts amounts of data" and some way of "filtering the essentials to decision makers at every level" [Ref. 12: p. 18]. Without such a means to manage this "information explosion", decision-makers faced with complex decisions and short time frames must rely soley on their own heuristic problem-solving abilities which are limited by small short term memory capacity and the serial, one-process-at-a-time mode of operation [Ref. 13: p. 40]. Because the nature of modern warfare involves tremendously fast and accurate weapons, there will be no time to perform this relatively slow mental problem-solving process for optimal solutions. While "satisficing," or "settling for a good-enough" solution may serve the needs of other decision makers [Ref. 14: p. 449], it is not a desirable method for

problem-solving when the consequences can affect the lives of men or the defense and reputation of the country.

The heuristic process of human decision-making can also result in distortions or biases [Ref. 15: p. 119]. The decision maker will search for relevant information, but will use only that which can be made available in the given time frame. He may interpret data differently depending on the order or method of presentation. He may select for retention only that data or information which he understands, or in which he has particular interest or knowledge. His expectations may prevent him from accepting the significance of contradictory information. The frequency of recent events can cause the decision maker to overlook the more crucial measure of rate of occurance. Variables may be erroneously correlated and inferences can be inappropriately derived from insignificantly small samples. These are just a few of the problems associated with unaided human decision making. The consequences for command and control decisions could be at best inefficient, at worst, disastrous.

D. DSS FOR COMMAND AND CONTROL

One method to improve the effectiveness of command and control decision making while eliminating at least some of these human biases, is to provide commanders with decision support systems [Ref. 16: p. 45]. A prototype DSS, the Tactical Flag Command Center (TFCC), is currently under

development and will provide Navy Officers in Tactical Command a "battle station which is automated to assimilate and display organic and non organic sensor tactical data" and will "enable him to coordinate and control assigned tasks in the increasingly complex tactical situations..." [Ref. 17: p. 32-33]. Other such systems are being planned to support commanders in all services.

Evidently the need to support decision makers in all three phases of decision making has been recognized. DSS may well be the answer. However, the fielding of such systems cannot be done successfully without careful planning and integration into an overall systems architecture. Command and control systems must be interoperable and survivable if they are to serve decision makers in combat environments. They must be integrated with complex weapons systems and thus incorporate some well-defined strategies and tactics. Furthermore, they must be affordable and take into consideration life cycle costs of maintenance.

The design of command and control DSS is much more complicated than that of a DSS intended for commercial uses. The following chapter will attempt to identify some of the major difficulties associated with developing such a system for command and control.

III. FITTING A DSS INTO THE COMMAND AND CONTROL ARCHITECTURE: ORGANIZATIONAL AND TECHNICAL CONSIDERATIONS

A. IMPLEMENTING NEW TECHNOLOGY

A DSS cannot be bought 'off the shelf' and simply "plugged in." Instead, the design and implementation must involve analyses of (1) the implicit affects upon the users and upon the context or organization in which they operate, and (2) limitations or requirements imposed by the supporting technology. Too often, the implementation of a new technology has been viewed as a "discrete-entity" process in which the technical merits of the new system(s) would determine effectiveness, independently of the specific characteristics of the organization [Ref. 18: pp. 7-8]. Such a practice is at least partly responsible for the lack of integration of the various components of the current command and control architecture [Ref. 19: p. 16].

A DSS is a form of technology in that it is a technique by which an organization or individual transforms inputs to outputs and which involves equipment, automation, and problem-solving methods. Thus, the implementation of a DSS can "require subsequent changes in task, structure or individual" [Ref. 20: p. 126]. Some of these changes may be easily predicted, some easily quantified in terms of cost.

More thoughtful analyses usually result in the identification of affects which are not readily quantified in terms of expected costs [Ref. 21: p. 223].

An attempt to estimate the costs associated with the implementation of a DSS for command and control purposes in the military will be very difficult, for there has been very little effort to develop a theory of current command and control decision making processes [Ref. 8: p. 45-49, Ref. 22: p. 45-49]. A cost/benefit analysis would be extremely difficult, if not impossible, without some understanding and ability to quantify, for purposes of comparison, the effectiveness of the current methods of command and control decision-making.

It is possible, and highly advisable when introducing a new system into an environment characterized by high technology and low structure (low level of integration), that some attempt is made to identify the "area of change" and perform what is has come to be known as a "risk analysis" [Ref. 23: p. 325]. Such a risk analysis is undertaken for early identification of potential problem areas and appropriate managerial or technical means by which to lessen the risks.

This chapter presents some organizational and technical factors which may require consideration by those who are responsible for the development of a command and control DSS.

The list is by no means complete, for depending on the particular situation and environment there will probably be more specific factors which will also require attention. The intent here is to develop an appreciation for some of the generally-applicable, but often neglected, organizational and technical factors which can affect the performance of a DSS in a command and control setting.

B. ORGANIZATIONAL FACTORS

1. Strategic Balance

Dramatic improvements in our command and control capabilities could have the effect of negating or reducing one or more perceived advantages of an adversary's weapons capabilities [Ref. 24: p. 4, Ref. 25: p. 248]. It would then be possible that the new command and control capability may itself become the subject of strategic arms negotiations [Ref. 26: p. 424]. If the DSS should incorporate real-time satellite data for an improved ability to "scan the battlefield," it may well raise questions as to whether this will increase or decrease the likelihood that nuclear weapons will be used [Ref. 27: p. 26]. The impact of new command and control capabilities on the strategic balance and on arms talks will largely depend on whether the new capabilities are perceived by our adversaries, especially the Soviet Union, as offensive or as defensive capabilities [Ref. 25: p. 246].

2. Centralized vs. Decentralized Command Authority

Depending on the communications capabilities provided in the design, a command and control DSS may further the trend towards centralization of command authority. If the DSS is designed to meet the objective of enhancing communications among the various echelons of command, it may provide central headquarters authorities with rapid feedback of subordinate actions and with the ability to monitor in a real-time manner, the behavior and events at the lower echelons [Ref. 20: p. 177]. This will be viewed favorably by those who feel that the threat of escalation to nuclear exchange mandates central control during any conflict [Ref. 20: p. 141, Ref. 28: p.8, Ref. 29: p. 266]. Others argue that commanders at the level of engagement have neither the time nor the inclination to accept control from remote authority [Ref. 30: p. 45, Ref. 31: p. 23, Ref. 32: p. 20].

Computers themselves do not enforce centralization or decentralization of authority. The choice is one of strategy and politics. The issue has already attracted much debate and has produced concepts of command and control which differ as to degree and location of control and responsibility. The Composite Warfare Commander and the Fleet Command Center concepts are two examples, the former advocating decentralization of control of warfare mission areas to at least 3 warfare commanders, the latter holding that control

by safely remote experts will simplify decision-making for on-scene commanders.

Before it will be possible to establish the information requirements of the users of a proposed command and control DSS, it will be necessary to agree on this aspect of command [Ref. 33: p. 31, Ref. 34: p. 418].

3. Defense Strategy

If the DSS is to provide the commander with such capabilities as threat evaluation, targeting prioritization, and situation analysis, it will necessarily involve models which cannot be designed without a clear definition of defense strategy and associated tactics. Critics argue that no such clearly defined strategy exists [Ref. 35, Ref. 36: pp. 9-12, Ref. 37, Ref. 38: p. 14]. Others suggest that current strategy has fallen out of step with the new threats and new weapons capabilities, especially in that forces and tactics are organized for a war of attrition when modern warfare's dispersed and decentralized characteristics more appropriately call for maneuverability and deception [Ref. 39: p. 18, Ref. 40: p. 33, Ref. 41].

The role of command and control capabilities and facilities in supporting the defense strategy must also be defined in order to design and implement an effective command and control DSS. Today there are no clear statements of

objectives for command and control support of the forces [Ref. 9: p. 52].

4. Interoperability

In the past, disregard for the interdependencies of various command and control systems has resulted in "separate programs, different rates of evolution, different protocols.." [Ref. 19: p. 18]. Don Latham, DUSD for C3I, referred recently to the almost unbelievable interoperability problems which have resulted. The present command and control resources "must be integrated into an overall plan to insure efficient employment and to avoid duplication of capabilities in future procurement" [Ref. 42: p. 2].

Interoperability of command and control systems is not an issue which can be addressed as an afterthought. Modern warfare with its broad area sensors and long range weapons requires that information be rapidly and reliably exchanged among systems at a variety of levels of command, between forces of the various services and between the United States and its allies [Ref. 43: p. 45]. It may even be advisable, considering the confusion and uncertainty surrounding the scene of future warfare [Ref. 44] and the constant threat of escalation, that our command and control systems be designed for "adversarial communications," or interoperability with non-friendly forces [Ref. 45: p. 90].

While it may be neither feasible nor desirable to design a given DSS for interoperability with all of the major systems, identification of desirable connectivity in the early stages of the system development cycle will reduce costly efforts to upgrade the system for such a capability at a later date.

5. Command Responsibility

The research involved in the preparation of this thesis uncovered not a single mention of the issue of responsibility for results of command decisions which are based on the information provided by a command and control DSS. Nevertheless, the issue seems worth mentioning; perhaps it will be raised officially once DSS actually become operational in command and control settings.

If the commander today is to be provided with a set of models and data to help him deal with the so-called data-explosion, then will he still be held responsible for the accuracy of those models and data? If the DSS is to be used under combat or crisis situations, will the commander be expected to assess the validity of the results of his queries to the system. It is not inconceivable that an error in the design of a model, or in the transparent data source could go undetected until the investigation which would follow an unfortunate, and possibly, a very costly, decision.

Clarification of this issue before asking commanders to use a DSS may at least serve to develop in those commanders a desire to fully understand the models and capabilities provided by the system. To neglect this issue is to risk reinforcement of a common tendency to distrust both models and computers--a result which will negate the potentials of DSS in command and control.

C. TECHNICAL CONSIDERATIONS

Command and control systems must be both reliable and flexible. The degrees of reliability and flexibility needed, and the ability to achieve them, is largely a function of the particular uses and operating environments of each system. The operating environment of a tactical command and control system presents more design problems than that of a strategic system due to the more restrictive availability of maintenance support, power, and space aboard mobile platforms. The following technical considerations for the design of a command and control DSS are discussed in terms of flexibility and reliability and apply specifically to tactical systems. Some of these comments may prove equally applicable to strategic systems.

1. <u>Flexibility</u>

The rapidly changing nature of the command and control environment and of computer hardware and software technology calls for a great deal of flexibility in the

components of the DSS. The modular concepts of software engineering as described by Constantine, Myers and Stevens [Ref. 46: pp. 115-138] will be useful for a command and control DSS. The basic idea is to design the system as a set of loosely-coupled segments where any one function is fully contained within a single segment, or module. This allows the isolation into separate modules of the various likely "areas of change." The same modular concept can be applied to the design of the hardware components at the box, board or chip level [Ref. 39: p. 2]. While the details of the processing techniques should be left to the contractor, the modular approach to design can be specified in the contract as a mandatory equipment specification [Ref. 47].

The following points emphasize the need for command and control software to be designed for flexibility:

1. Algorithms and data may need frequent revision due to the rapidly changing capabilities and nature of weapons systems and threats. Modular software, with its separation of "areas of change," will greatly reduce reprograming effort and cost and will lessen the risk of negatively affecting other portions of the software.

2. User needs vary across users and individually over time. Some users prefer graphic displays over tabulated data. Some users will need more "help" instructions to operate the systems. Some will become expert users with experience and would become frustrated if there were no means to bypass the more basic help instructions for faster response [Ref. 48: pp. 16-17].

3. The decision-making processes for peacetime operations are distinctly different from those which are necessary for combat operations [Ref. 49: p. 93, Ref. 50: p. 15]. The DSS should support both of these decision-making processes and provide for a smooth transition from

one to the other. This means that while the system should provide different models, data and response times, it should not require any major changes in operation.

4. The system will require changes as more is learned about command and control decision-making in general, and as the user provides feedback as to how the system could better meet his needs. Current knowledge of command and control decision-making is incomplete, and as weapons and tactics undergo constant changes, the study of such decision-making will be an ongoing effort [Ref. 22: p. 34, Ref. 8: p. 96].

5. A modular design will reduce software maintenance efforts, which typically account for an estimated 67% of total effort expended on large-scale software systems [Ref. 51: p. 204]. Maintenance involves correcting newly-discovered errors, performing planned updates and making adjustments for change in local conditions (such as changes in the hardware). Approximately 70% of the total cost of software systems over the life cycle occurs during this maintenance stage [Ref. 51: p. 204]. This figure could increase if the current upward trend in the cost of programming continues [Ref. 46: p. 136]. Simplified software maintenance is also particularly important for tactical systems due to the difficulty in providing skilled personnel to perform the maintenance and due to the impact of downtime on mission performance.

6. A modular software design will permit separation of the communications processing subsystem and thus allow for flexibility in sources of data input [Ref. 52: p. 96]. This is an important consideration since communications media are subject to both natural disturbances and, in conflict, intentional disruption. The communications subsystem should be readily and easily reprogramable for such changes and should have no affect on the rest of the system, save perhaps a short time delay.

7. If the database is limited by storage capacity, it may be desirable to provide off-line disk storage for different communications subprocessing programs, models, and data files.

2. Reliability

A command and control DSS will no doubt be a great decision-making aid in peacetime. The commander will

appreciate a system which helps him filter and make effective use of all the data available to him. He will also grow accustomed to have such aid. The DSS would be counterproductive, however, if it ceases to function during a combat situation when he may most need it. It is therefore necessary to take every precaution to "harden" the system and to ensure the integrity and availability of its supporting data, models and hardware. The following discussions of hardware, communications and data model reliability will point out some of the potential problems which, if considered during the early development stages, can be countered with appropriate hardware and software techniques.

a. Hardware Reliability

Defense system requirements are vastly different from those of the commercial sectors. Command and control systems, in particular, require very reliable and rapid processing of real time data streams [Ref. 53: p. 358]. Furthermore, defense systems, especially tactical systems, are constrained by weight, power, and size limitations and are subjected to far more extreme environmental hazards such as high temperatures, radiation and vibration [Ref. 54: p. 346].

The introduction of new hardware to support a command and control DSS provides an opportunity to improve

reliability through the use of 'Very Large Scale Integration' or 'Very High Scale Integrated Circuitry' (VHSIC).

(1) VHSIC Technology. Commercial semi-conductor designs cannot meet the speed, density and reliability requirements of a command and control system [Ref. 55: p. 340]. The VHSIC program was initiated in 1980 by the Department of Defense to overcome these technological barriers with the more capable chip. The new chips will provide more processing capability and higher throughput capacity. The reduction in vulnerable interconnections among chips which results, serves to increase reliability. The reduction in feature size of integrated circuits on these chips also allows for built-in testing techniques which can greatly simplify maintenance-- a distinct advantage in the tactical field [Ref. 56: p. 344].

(2) EMP Shielding. Solid state circuitry is very vulnerable to electromagnetic pulsing. Most new command and control systems programs have set aside funds for protective Faraday shielding at the "box" level. The larger the "box," the more expensive the shielding. VHSIC will greatly reduce the sizes of these components, or boxes, and thus provide savings in shielding costs [Ref. 57: p. 240, Ref. 5: p. 27].

(3) Hardware Maintenance. Although the reliability of individual electronic components in military

systems has steadily improved over the years, the complexity of these systems has grown even more rapidly as a result of escalating performance demands. The amount and complexity of unscheduled maintenance is unacceptable and degrades mission performance [Ref. 58: p. 11, Ref. 59: p. 15]. VHSIC technology promises to greatly improve performance and reliability as well as the extra advantages of reduced "payload:"

> "...VHSIC technology could be used to reduce size, weight, power, failure rate, and unit cost, each by factors ranging from 20 to 200; the processing throughput could be increased by a factor of about 150" [Ref. 56: p. 343].

b. Data Communications Reliability

(1) The Problem. Much of the data needed for a *command and control* DSS will be provided by real-time transmission over communications media. As mentioned earlier, the DSS should not be affected by the need to switch to an alternate path or medium in the case of signal loss on the original path. It is also necessary to plan for the inability to reestablish communications, or the complete loss for an extended period of time of critical data sources.

Signal degradation and path failure occur even in peace time due to equipment failure and inclement weather. The probability of losing communications circuits increases greatly when hostile forces deliberately attempt to jam, interfere or otherwise sabotage communications capabilities and facilities. Threats range from the

destruction of fixed communications stations and satellite earth terminals to laser attacks on the satellites themselves. The Soviets are developing laser-capable spacecraft which will threaten our communications satellites, and already they have the capability to blind our low-orbit (100 miles) satellites with their land-based laser devices [Ref. 60: pp. 16-19]. The threat to our satellite communications capabilities is an especially serious threat to the Navy as its tactical command and control is heavily reliant upon satellite links [Ref. 61: p. 49].

A NATO official describes the vulnerability of the data communications which support the NATO Air Command and Control System (ACCS) [Ref. 62: p. 16]:

> "We see as a critical and vulnerable element of the ACCS the susceptability to jamming of its tactical communications links, with the probability that the flow of essential weapon control data would disrupted and the decision making process would be seriously inhibited at all levels."

The October issue of Defense '82 describes the vulnerability of "the major part, if not all, of our existing C3 capability" to a coordinated Soviet attack with air and sea-launched cruise missiles and long-range bombers [Ref. 63: p. 8]. Nuclear weapons pose an even greater threat in that Electromagnetic Pulses (EMP) can be carried for long distances in unpredictable directions by the atmospheric pressures. EMP is known to have the effect of "freezing" solid state circuitry, at least temporarily. A small two

megaton burst can damage an unprotected satellite up to 22,500 miles away [Ref. 64: p. 27].

(2) Solutions. Lt. General William J. Hilsman, Director, Defense Communications Agency, expressed his concerns in a recent interview that the military communications system is too heavily reliant on fixed communications stations. Both he and the NATO ACCS officials support the theory that modern day warfare would be better supported by distributed data communications which do not rely on the continued operation of any one node. Already some C3 systems , such as the Joint Tactical Information Distribution System, are being developed to facilitate secure, flexible and jam-resistant data and voice transfer in real time among the dispersed and mobile elements of the military services [Ref. 65: pp. 15-17]. The concept of data distribution has not been easily accepted. It may be many years before the communications system architecture can be changed for less reliance on fixed stations, due to bureaucratic and organizational inertia and the general difficulty in getting command and control systems approved and funded through Congress [Ref. 58: pp. 11, 14].

The use of high frequency (HF) communications links will also add appreciably to the probability of successful communications. The reliability in peacetime operations of satellite links and the memories of once

unreliable HF path quality have resulted in the neglect of the HF frequency band. The new "chirp-sounder" equipment, currently being fielded by the Defense Communications Agency, has increased HF path reliability to 90% [Ref. 58: p. 12]. Chirp sounders automatically sample the spectrum for tuning into good frequencies. Also, the HF spectrum has a unique capability to propagate beyond line-of-sight using reasonable size antennas and relatively modest output power.

Command and control DSS should be designed to take advantages of the capabilities of the HF frequency band as either a primary system or as backup to a satellite or other relay system. Jamming resistance can be provided by the use of frequency-hopping techniques and coded burst communication [Ref. 66: pp. 380-388].

Communications reliability can be also be improved by the use of redundant transmissions or dedicated back-up circuits. An analysis of information needs and available communications paths should identify the most survivable paths and backups for the high priority data needs. The DSS can then be designed to accommodate these communications media and to allow for flexibility to make necessary changes. The data analysis may also indicate a need to develop contingency plans for cases when communications cannot be reestablished for particular circuits. The loss of data may mean the inability to use

certain models available in the DSS. The commander should be aware of the affects of data communications loss on DSS operation and of possible alternate methods of receiving data (over voice circuits) for possible manual insertion.

The point here is planning. The Soviets have invested heavily in Electronic Counter Measures, or what they call "Radio Electronic Combat" [Ref. 67: p. 10]. Until our C3 systems are fully survivable, it would be dangerous to allow commanders to become accustomed to or dependent on a decision-making system whose operation is dependent on the availability of vulnerable, limited data sources, without providing contingency plans.

c. Model Reliability

Models are what distinguishes a DSS from other information management systems. A command and control DSS will employ models to integrate data from a variety of sources, including real-time sensor sources, for the purpose of situation analysis. Models may also be provided within the DSS for performing combat simulations for planning purposes.

Thus models used in a command and control DSS can range from the straight-forward algorithms used in calculating distance-to-target to the more complex, multiple variable, multiple algorithm models of threat evaluation. A Comptroller General Report to the Congress [Ref. 38]

distinguishes models as those which solve "rigorously quantifiable" problems and those which solve "squishy problems."

While all models are subject to design errors, it is the "squishy" problem-solving models which deserve particular attention by those who intend to have them incorporated into a command and control DSS. Once these models have been approved for the system, the intended users should also be made aware of both the capabilities and limitations of each model. Where possible it is even advisable to provide for user participation in the design of models. User understanding is important both for building trust in the system and for avoiding gross misinterpretation of results [Ref. 68: p. 57].

(1) Assumptions in Models. Modelling is more an art than a science. It is impossible, in many cases, to quantify some of the variables which contribute greatly to the outcome of events, such as the effects of darkness or stress, the complex interactions of weapons systems, and the roles of C3 and counter-C3. In other cases, it is necessary to omit even some quantifiable variable inputs due to the inability to process all the inputs in the necessary time frame. The model-builder must determine which variables are the most critical and of those, which can be included included for realistic processing times. His or her

assumptions, then, are one of the weaknesses inherent in the modelling process [Ref. 68: p. 56].

(2) Data Verification. Another basic weakness is the inability to verify data. Many of the calculations performed by combat models depend on quantifiable performance ratios of various weapons systems. Some of these weapons have had very little testing under realistic conditions. Nuclear weapons have undergone virtually no realistic testing. Even where data is available, it is subject to frequent change and rapidly outdated by weapons system technology. Sources for weapons data have sometimes been historical, often from unlocatable or inaccessible classified documents. Some figures are sheer estimates on the part of analysts. Currently there exists no single complete source of weapons data; the Command and Control Technical Center in the Pentagon has just recently begun to establish such a data bank. The lack of standard data has resulted in models which vary widely throughout the Department of Defense [Ref. 69: pp. 73-78]..

(3) Aggregated Models. Aggregated models are perhaps the "shakiest" of all models. They lump together similar types of weapons into a composite index which is then used to represent the combat power of a military force. Both the model and the input data for such aggregation involve critical assumptions about tactics, rates of fire and

distribution of that fire [Ref. 69: p. 56]. Use of such models should be for general planning and comparison purposes only.

(4) Model Interpretation. If the builders of models could explain and document their assumptions to the end users, the current problem with interpretation might be somewhat alleviated. As it is, modellers have limited and infrequent contact with users or their organizations [Ref. 69: p. 31] and documentation is as much a neglected item as it has been with most other Department of Defense software systems.

(5) Combining Models. In defining information needs, it sometimes seems desirable to utilize outputs of one model as inputs to another [Ref. 69: p. 79]. It can be done, but experts warn that the programming effort will be horrendous [Ref. 70: p. 99, Ref. 71: p. 340]. Furthermore, errors in the first model can be so compounded by subsequent models as to invalidate the results [Ref. 68: p. 57].

(6) Model Validation. A last warning, from a NATO operations analyst who creates combat models for a living, should emphasize the uncertainty inherent in the processes of modelling [Ref. 68: p. 55]:

> ..in spite of the intellectual resources devoted on both sides of the Atlantic to modelling techniques, there is no agreed, coherent theory or set of criteria by which one can asses the suitability of any given model.

The point in this section on Model Reliability is not to discount the advantages or deny the need for the use of models, but instead, to develop a sense of caution in order that command and control DSS designers will demand documentation of assumptions in models and of data sources for models which will eventually support a decision maker's judgement, for [Ref. 69: p. 73]:

> .. when that judgement is 'extended' by a model -- a model that uses unverified assumptions that go beyond science and objective fact--how can the decision maker be sure that the model is in fact, serving as an extension of his/her own judgement...

The next chapter on implementation presents the concept of a command and control system test bed. The test bed simulates the command and control environment and could be used as one check for validity of models. The real test will be actual combat use. Careful design and documentation will reduce the risk of costly error in actual use.

IV. COMMAND AND CONTROL DSS IMPLEMENTATION

The evolutionary or prototype approach to implementation of a DSS is especially applicable to systems designed for command and control purposes:

> ...every design problem begins with an effort to achieve fitness between two entities: the form in question and its context. The form is the solution to the problem; the context defines the problem. In other words, when we speak of design, the real object of discussion is not the form alone but the ensemble comprising the form and its context. Good fit is a desired property of this ensemble into form and context [Ref. 72: p. 33].

Fitting a DSS into the very complex context of command and control will require the flexibility of an evolutionary development approach. While government regulations and the military personnel turnover problem will complicate the implementation process, the results of a prototyping approach will better meet commanders' decision-making needs in the rapidly changing command and control setting.

A. THE TRADITIONAL APPROACH TO IMPLEMENTATION

The traditional approach to systems acquisition and implementation, still used for most command and control systems, follows a sequential approach from requirements definition, to advanced development, to fielding and support. Even when this sequence of events is iterated, the ultimate goal is the "freezing of the specs" in the requirements

definition phase. While this traditional process seems reasonable for weapons/platform acquisition, it is not advisable in unstructured settings [Ref. 73: pp. 1-8] as it intimidates the decision-makers, forces premature closing on problem-solving approaches, and inhibits the important learning and search processes that are essential for managers to undertake in addressing less strctured tasks.

In general, DSS will experience a very short periodicity-- or serviceability--before requiring hardware, or more likely, software changes for restructuring, updating or expansion [Ref. 73: p. 5]. The following characteristics apply to command and control systems and should serve to explain their short periodicity [Ref. 74: pp. 19-20]:

- Only a few of a kind are procured.
- The systems are embedded in larger systems.
- The measures of success are difficult to define.
- Continuity of operations is essential.
- The systems embody changing tactics and procedures.
- The systems are software-dominated.

A seventh characteristic which affects command and control systems periodicity is the unpredictability of funding [Ref. 58: p. 14]. Planned capabilities may have to be dropped when funds are cut in the eleventh hour.

Thus a command and control DSS will be a unique set of software, custom tailored but flexible enought to meet the

specific decision-making styles and information requirements of a commander who operates in an unpredictable and rapidly changing environment. It would be very difficult to determine at once all the objectives of a given system or how the users will respond to particular configurations and capabilities.

B. PROTOTYPING

The prototype approach accommodates these uncertainties by phased implementation of versions, where the first version is a "breadboard" or minimum requirements system. The determination of the minimum requirements will require considerable time and effort up front [Ref. 74: p. 25]. Subsequent versions, providing funding is available, can add new capabilities, make modifications, or incorporate advantages of new hardware or software technologies, all based on user feedback from in-context testing. The concept of modular hardware and software design is highly compatible with the prototyping approach to implementation. Together, these techniques can produce a system which is designed from the start to accommodate growth and change and to accept "graceful insertion" of new technologies [Ref. 75: p. 39].

C. BENEFITS OF PROTOTYPING

Some of the benefits of prototyping are, briefly [Ref. 76: p. 65]:

1. Reduction of Total Cost

Over one-half of the total software in command and control systems tends to be unique, costly, one-time development efforts. The modular approach to implementation, with its built-in expectation of change, reduces overall development and maintenance costs [Ref. 77: p. 50].

2. Reduction of Initial Risk

Instead of dedicating large dollar amounts and human resources to a long-term, "one-shot" program which defies evaluation until completion, prototyping allows minimum initial investments and constant evaluation. Success at each stage could make the next stage easier to justify and fund. Errors are more easier and less costly to track to sources, and corrections of errors are less likely to cause unexpected changes elsewhere in the system.

3. Slower Obsolescence

Changes in tactics, weapons or other decision-making criteria will not render the system obsolescent as it can be more readily adjusted to accommodate those changes.

4. Higher Operational Readiness

Prototyping can provide for the early fielding of minimum capabilities rather than the long delay in waiting for an entire system to be developed.

D. RESOURCE REQUIREMENTS FOR PROTOTYPING

The prototyping approach requires the availability and skilled use of advanced software techniques in order to facilitate the many changes to versions. The following resources will provide programming and design advantages which can speed the development effort and prevent the problems of constantly "reinventing the wheel" with each version [Ref. 72: p. 34]:

1. DBMS

A database management system (DBMS) will provide for rapid and relatively-easy creation, revision, and extension of data access methods, storage structures and security measures. Ideally, the DBMS will have extensive reporting facilities for design management purposes.

2. Generalized Input/Output Software

Output formats and displays can be more rapidly designed with the use of report generators, report writers and query languages. Generalized input software automates the editing, validation and error correction procedures which would otherwise complicate and lengthen the process of changing the database.

3. Programming Languages

While most command and control algorithms may require the efficiency of assembly language, high level languages can

be used where efficiency is not paramount, for simplified coding, testing and documentation.

4. Modelling

The need for models has already been discussed. The use of a model base management system for the integration of models into a "model bank" is advisable for rapid construction and use of models [Ref. 70: pp. 98-110].

5. Time

To the above resources as offered by Naumann and Jenkins, it seems necessary to add the element of time as a resource. Prototyping depends on user evaluation in context. Thus the user must be able to dedicate sufficient time, away from his other duties, to experiment with and evaluate each version. For some command and control systems it may prove difficult to test versions on the very platforms in which they will operate. Tight operating schedules may indicate the need to make use of a command and control test bed to simulate the intended operational environment [Ref. 78: pp. 103-106].

E. DISADVANTAGES OF PROTOTYPING

All methods have drawbacks. The following disadvantages apply to prototyping for most DSS [Ref. 79: p. 22]:

- Large amount of user time required
- Requires highly talented system designer
- Possible reprogramming needed for efficiency

- Lack of standards and documentation can complicate maintenance

- Highly susceptible to user/implementer turnover

- Continuous change can be frustrating

- Unweildy with more than 2 or 3 users

The user/designer turnover problem is one that the military, with its policy of rotation, will have to live with. In at least one DSS case, it has resulted in the complete failure of the system [Ref. 80: pp. 542-455]. The other problems mentioned by Alter, can be approached with good planning and use of resources and the establishment of good user-designer relations.

A problem not mentioned by Alter, and probably unique to federal systems acquisition, is the difficulty in getting away from the traditional systems development process. A new Department of Defense Instruction 5000.2 for evolutionary acquisition has not been applied consistently "partly because the concept of evolutionary acquisition is not well understood, and partly because of resistance to the special management procedures and changes..which are required" [Ref. 81: p. 9].

F. SUMMARY

The rapidly changing environment which distinguishes command and control calls for an acquisition and implementation strategy which allows for greater flexibility

and user involvement than is possible with the traditional phased development process. Personnel turnover and rigid governmental acquisition regulations may complicate the process, but the prototype approach to implementation seems the most promising for the accommodation of change, growth and new technology insertion, as well as budget limitations, of command and control systems.

V. SUMMARY AND CONCLUSIONS

Command and control DSS have the potential to fulfill the information requirements of individual commanders while also filling the gap of distributed decision-making between service echelons and across service systems. Already there is a strong movement underway to apply the concept of DSS to command and control purposes. The command and control DSS which are currently under development are breaking new ground. There is as yet, no one source of guidance for the designers or project managers of these systems. Current texts have been written for strictly commercial purposes such as banking and finance. These texts provide a wealth of information about the design techniques used in creating DSS, but do not address issues which are critical for the design of military DSS.

Military decision-making involves several echelons of command authority, real-time communications-dependent data, highly unpredictable events and results which can affect national defense. For these reasons, careful consideration must be given in the early development phases, of the following issues:

- The affects of the DSS on the organization's decision-making processes
- Optimal use of available DSS capabilities

- Interoperability with other systems as necessary
- Identification of tactics and strategies
- Legal issues of command resposibility in use of DSS
- Current and expected requirements for reliability
- Support for both peacetime and combat decision-making
- Decision-making styles of users
- Likely "areas of change" for separation into modules
- Availability/ease of software and hardware maintenance
- Reliability of data communications sources
- Protection against EMP
- Possible advantages of VHSIC
- Reliability of supporting models
- User understanding and acceptance of models
- Advantages of evolutionary approach to implementation
- User involvement in design and implementation

These are all considerations which will involve approaches and problems unique for command and control systems. The answers will not be found in current literature on DSS. Some suggestions have been made in the preceeding chapters, but specific solutions to problems will, of course, depend on the particular context and applications of each system. It is hoped that this thesis will stimulate further research and interest in the identification of methods and techniques which will result in more capable, reliable command and control Decision Support Systems.

APPENDIX A

A SUMMARY OF CURRENT LITERATURE ON DSS

The concept of a DSS has evolved since Michael S. Scott Morton's description in the early 1970's of a management decision system. Today a standard definition of a DSS is:

> ...an interactive computer-based system which helps decision-makers utilize data and models to solve unstructured problems [Ref. 82: p. 40].

The following characteristics of a DSS were determined by 300 users, developers, researchers and vendors at the First International Conference on Decision Support Systems in June 1981 [Ref. 82: p. 6]:

- Aimed at the less well-structured, underspecified problems typically faced by upper-level managers
- Combine use of models or analytic techniques with traditional data access and retrieval functions
- User initiated and controlled
- User-friendly with rapid response
- Tailored to individual decision-maker's style and information needs
- Flexible and adaptable to accommodate changes in environment and decision-making approach of user

Some additional characteristics of a DSS as presented by authors of important texts on the subject:

- Focus on improving effectiveness of manager's decision process [Ref. 21: p. 2]

- Provides managers with access to both internal and external data sources [Ref. 82: pp. 31-32]

- Usually requires separate, or extracted, data base to accommodate user's personal and unofficial data and information

A. DSS VS. EDP AND MIS

Before developing further these DSS concepts, the following descriptions of Electronic Data Processing (EDP) and Management Information Systems (MIS) may help to clear some of the difficulty and controversy with the terms DSS, MIS and EDP.

EDP was the earliest form of computer support to organizations. It involved automation of large-scale, batch, operations such as payroll, invoicing, inventory and record-keeping. The emphasis was on the automation of routine data or transaction processing. Basic EDP characteristics include [Ref. 82: p. 6]:

- Focus on data, storage, processing, and flows at the operational level

- Efficient transaction processing

- Scheduled and optimized computer runs

- Integrated files for related jobs

- Summary reports for management.

With the more sophisticated, third-generation computers and their economies of scale, higher-level languages, operating systems, remote terminal and query capabilities, organizations began in the latter 'sixties to develop more

integrated sets of specific data bases. These data bases tended to be centrally located and organized by functional applications. Such MIS systems are the most common type of computer support in organizations today. The introduction in the latter 'seventies of complex database management systems (DBMS) has permitted the sharing among functional applications of pertinent organizational data and information. Report-generation capabilities have made possible the request and receipt of summaries by managers, often from their remote terminals.

The name 'MIS' has been somewhat misleading. Most experts today contend that the rigid reports produced by MIS have had little significant impact on management decision-making processes [Ref. 83: p. 3]. Some critics have gone so far as to imply that "MIS is a mirage" which has merely created more data for the already over-burdened manager [Ref. 84: pp. 123-132].

In any case, the following characteristics are usually associated with MIS [Ref. 21: pp. 1-2, Ref. 82: pp. 7, 31]:

- Information-focused for middle managers
- Impacts structured tasks, where standard operating procedures, decision rules, and information flows can be reliably predefined
- Integration of EDP jobs by business function (personnel, marketing, etc.)
- Inquiry and report-generation capabilities

- Emphasis on efficiency (costs, turn-around time, personnel reductions)

- Indirect support for managers decision-making, in the form of reports and access to data

- Database restricted to internally-generated aggregate or historical data.

MIS continues to hold an important position in most organizations as is evidenced by the growing number of journals and articles devoted to the value of information, Information Resource Managers, database management systems, and other such concepts related to the development, maintenance and management of organizational information resources. Two recent and important factors, however, are beginning to stimulate interest in the more decentralized and personal DSS application of computers. One of these factors has been the increasing familiarity with and acceptance by managers of the capabilities of the computer. The second factor is the need to exploit the new hardware and software technology to help managers make better decisions in an environment which has suddenly become characterized by inflation, uncertainty, economic swings and governmental regulation [Ref. 21: p. 4]. The DSS emphasis on effectiveness is more appropriate for dealing with change than is the efficiency provided by MIS [Ref. 85: pp. 19-34].

B. EFFECTIVENESS VS. EFFICIENCY

While the ultimate goal of any manager or organization would be to achieve both effectiveness and efficiency, the two criteria of performance must be balanced and play different roles depending on the maturity and environment of the various organizational functions. Efficiency implies maximum output for minimum input. It is essentially programmatic in mature organizations operating in stable environments. Effectiveness, on the other hand, involves more judgement in identifying what must be done and how it must be done. It requires adaptation and learning, at the risk of redundancy and false starts. For example, while research and development can be thought of as a risky and inefficient investment of resources, it's purpose is usually to provide for future effectiveness [Ref. 21: p. 7].

C. STRUCTURED VS. UNSTRUCTURED

The above destinction between effectiveness and efficiency in decision-making is central to the concept of DSS and their application to unstructured or semi-structured problems faced by managers. Most texts on the subject of DSS's employ Herbert C. Simon's paradigm of problem-solving processes to explain the continuum of structured through unstructured problems. Basically, he has stated that the process of problem-solving involves three discernable, but iterative steps [Ref. 86: p. 6]:

- The intelligence phase--searching the environment for conditions calling for decision. Gathering data

- The design phase--inventing, developing, and analyzing possible courses of action

- The choice phase--selecting a particular course of action from those available.

Problems, or the process of problem-solving, then can range from the structured to the unstructured, depending on how easily identified are the information needs and processes involved in each of these three problem-solving steps. Structured, or as Simon calls them, programmed decisions are:

> ...repetitive and routine, to the extent that a definite procedure has been worked out for handling them so that they don't have to be treated de novo each time they occur [Ref. 86: p. 7].

That is, each phase can be readily described and thus could be programmed for computer processing. Transactions for customers can thus be handled completely automatically at bank automated cash tellers.

Unstructured, or non-programmed decisions, on the other hand, are novel and consequential. Simon continues:

> There is no cut & dried method for handling the problem because it hasn't arisen before, or because its precise nature and structure are elusive or complex, or because it is so important that it deserves a custom-tailored treatment. ...the system has no specific procedures to deal with situations like the one at hand, but must fall back on whatever general capacity it has for intelligent, adaptive, problem-oriented action.

Most DSS experts agree that such problems remain unsupported by computers today and are left strictly to the manager's

judgement and experience. None of the steps in Simon's decision-making or problem-solving paradigm can be programmed. In the intelligence phase, we are unable to define the conditions that allow us to even recognize the problem. We are likewise unable, in the design phase, to specify how to create methodologies to solve the problem. An example of such a problem would be the forecasting of women's taste in shoes. No clear criteria can be identified for selecting a best solution in the choice phase. Thus, the entire problem is unstructured [Ref. 21: p. 95].

Most problems, however, fall somewhere between these two extremes and are called "semi-structured" problems. One or more of the phases of intelligence, design, and choice can be defined. This is where DSS can be the most effective. Semistructured problems or tasks require the judgement of the manager or decision-maker for those unspecifiable phases, but can be supported by models or data which reflect the known criteria for the other phases. Often, with experience and knowledge gained over time, such problems can become sufficiently structured to permit total automation. Until then, however, the man-machine interaction provided in a DSS can provide more effective solutions for semi-structured problems.

D. INFORMATION NEEDS DIFFER

Three categories of managerial activity have been identified by Anthony [Ref. 87: pp. 24-27] as distinguishable in that, while each faces semi-structured problems, their information needs differ in scope, detail and currency. Strategic planners need aggregate data for long-range planning. Management control personnel need some degree of detail and operate in shorter-range planning to translate strategic plans into resource requirements. Operational control personnel use detailed and current data for direction of actual production.

Anthony's framework has implications for the design and development of DSS's. First, it is apparent that all levels of managerial activity are involved in semi-structured problem solving. Thus DSS application in the organization is not restricted to top management. Secondly, given the differing information needs and characteristics associated with each level, it follows that DSS's must be highly tailored to the specific use or developed with sufficient capabilities and flexibility so as to permit rapid transition from one type of task or problem to the next. It is also evident that the supporting data base for DSS's in operational control would differ radically from that which would support DSS's in the strategic planning area. The same can be said for the types of models incorporated in DSS's

which support these different managerial activities. Furthermore, the design, development and implementation of DSS's among different managerial activity levels would necessitate the involvement of different specialists from the systems group in the organization.

E. COMPONENTS OF A DSS

To realize the potential of a DSS in any of the organizational contexts described above, a set of hardware and software components must be designed and assembled. While the particular design will depend on the specific application of the DSS, some generalizations can be made about the basic components. First, and most importantly, a DSS involves the human decision-maker. This decision-maker, usually a manager, operates in a unique environment and is responsible for a given number of tasks. Figure A-1 illustrates the relationship between the decision-maker, the task, the environment and the collection of components which make up a DSS.

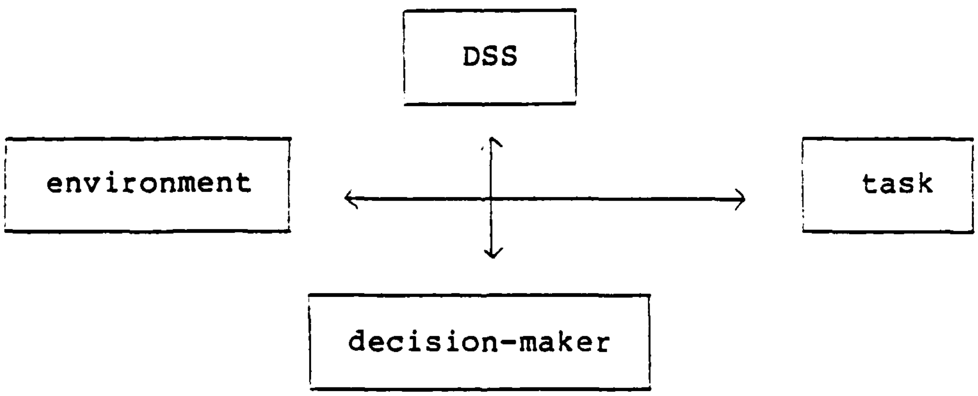

Figure A-1. Man-Machine Environment

The components which make up the DSS include a data base, a model base, and a dialog language which interfaces the decision-maker with the system. Each of these components requires an associated management system to permit manipulation and access by the user. Figure A-2 depicts the logical relationship of these components and their respective management systems [Ref. 82: p. 29].

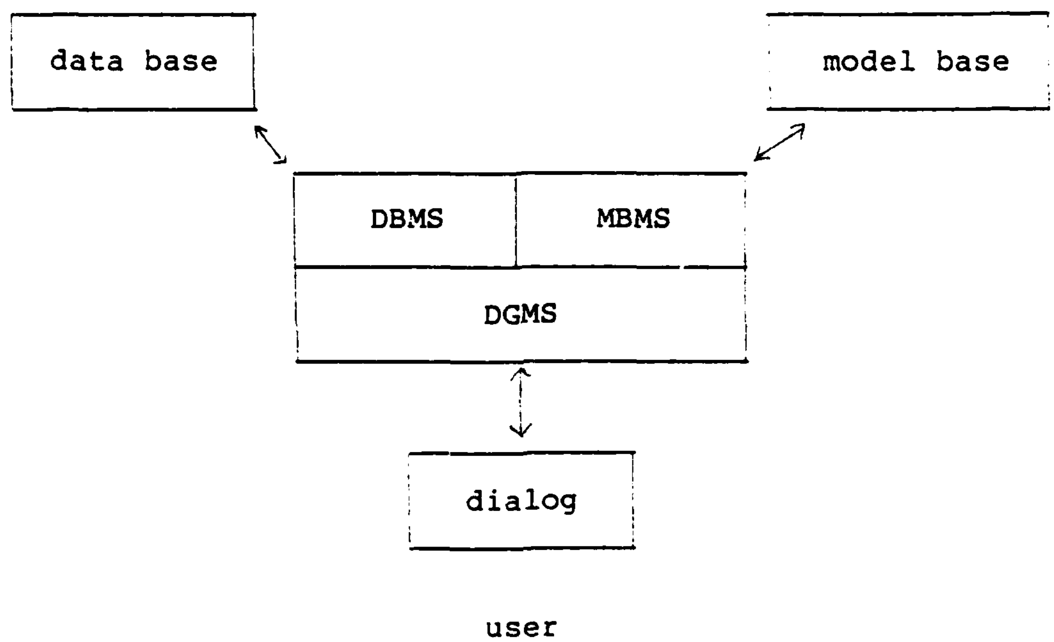

Figure A-2. DSS Components

1. The Dialog Subsystem

The dialog subsystem of a DSS is the DSS in the eyes of the user. All of the capabilities of the DSS must be articulated and implemented through the dialog. This dialog

subsystem can be further broken down into three parts [Ref. 81: 2p. 30].

a. The Action Language

What the user can do in communicating with the system. May include such options as the availability of a regular keyboard, function keys, touch panels, joy stick, voice commands, etc.

b. The Display or Presentation Languages

What the user sees. The display language includes opinions such as a character or line printer, a display screen, graphics, color, plotters, or audio output.

c. The Knowledge Base

What the user must know to use the system effectively. May consist of a manual of available commands and their descriptions. May be displayed on the screen or available upon request with a "help" command.

The richness and flexibility of the dialog interface will depend on the strength and variety of these capabilities. The success of the entire DSS depends in large part on how user-friendly the dialog subsystem appears to the user. Managers seldom wish to learn complex languages or to memorize illogically-designated commands for functions. The more logical the commands and the more the dialog resembles natural language as employed in the context of the task at hand, the more likely the system is to be used and

appreciated by managers. The following capabilities of a dialog subsystem further enhance the chances of success of the DSS [Ref. 82: p. 31]:

- The ability to handle a variety of dialog styles, and to shift among them at the user's choice
- The ability to accommodate user actions with a variety of input devices
- The ability to present data with a variety of formats and output devices
- The ability to provide flexible support for the user's knowledge base.

Dialogs can take the form of question and answer routines, report format blanks, menu selections, or command languages. Most DSS will incorporate some combination of these for wider application and increased flexibility. They usually include other conventions to provide error messages, acknowledgements, verification requests, default values, and possibly override features for experienced users [Ref. 82: p. 207].

The choice of a dialog form is an important decision in the design of a DSS for two reasons: (1) an inappropriate format will discourage use of the DSS and thereby reduce its effectiveness, and (2) the dialog component of a DSS often constitutes the largest percentage of the total code in a DSS, and thus the most expensive [Ref. 82: p. 217].

The design of the dialog component should begin with an analysis of the decision-making process and environment of the user. Such an analysis would identify the communications style of the user, the response-time requirements, the desired outputs, and the required input parameters. The goal should be to provide effective representations or displays and understandable control mechanisms. In many cases, software packages can be purchased 'off the shelf' to meet the needs of the user and reduce development costs. Some applications, on the other hand, are so unique as to require programming, either in-house or by a contractor.

The effectiveness of a chosen dialog can be measured by number of errors, learning time, user perceptions and, although more difficultly, by effect on the decision-making process and its results. (i.e., number of alternatives analyzed) [Ref. 82: p. 207].

2. The Data Subsystem

The data subsystem of a DSS is visible to the user only through the use of the dialog to access desired data. Recent advances and developments in database management provide a number of powerful functions, often in the form of "off the shelf" packages. However, the data base of a DSS differs from that of a MIS in two significant ways; it is dependent on external sources as well as internally-generated

data, and it must accommodate individual user's needs for storing and rapidly accessing both personal and corporate data. For these reasons, it is often necessary to create for the DSS a separate data base, part of which is extracted from the general corporate data base (or MIS) and part of which is drawn from external data sources. Figure A-3 illustrates the concept of the extracted data base [Ref. 82: p. 32].

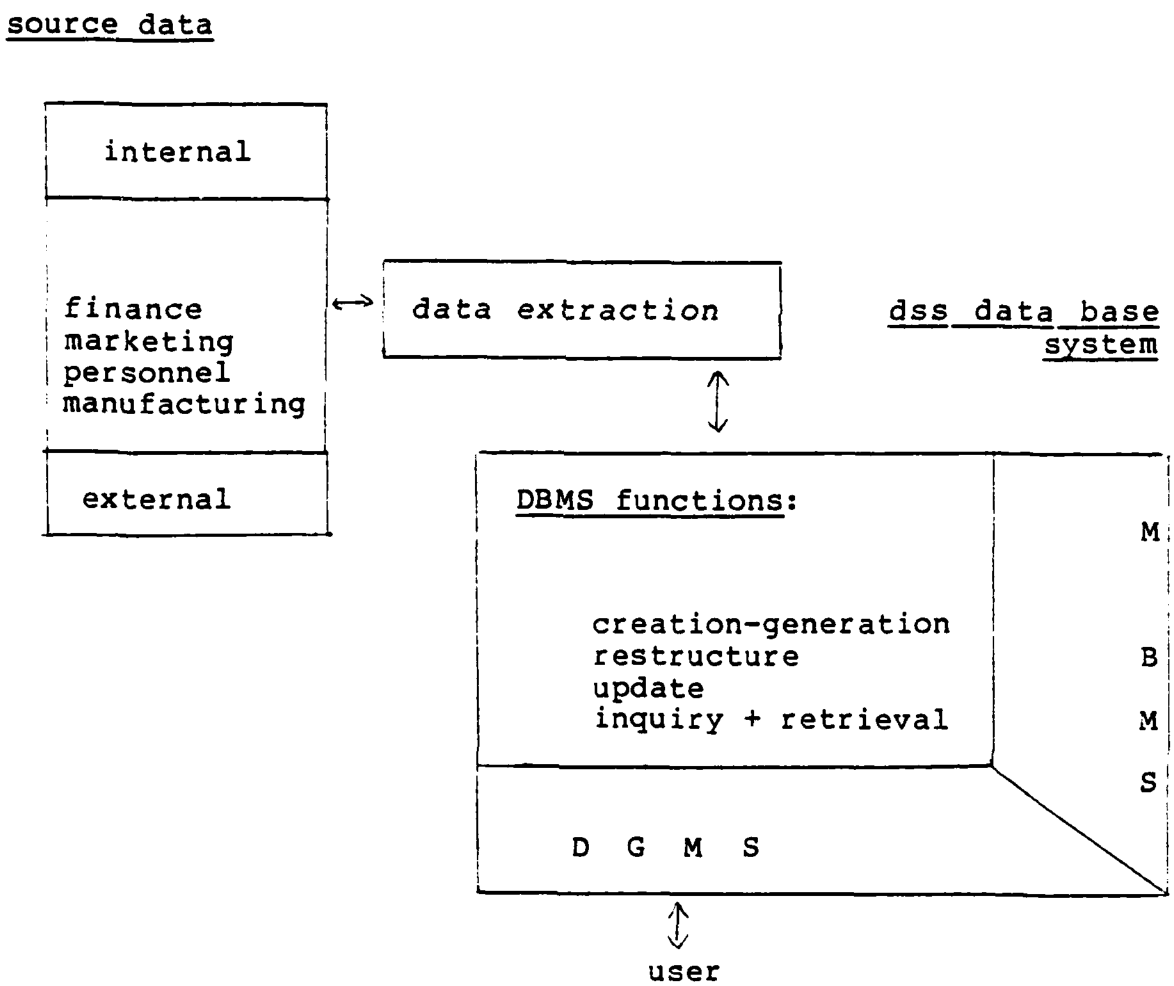

Figure A-3. Extracted Data Base

Carlson and Sprague identify some desirable features of a DSS data base subsystem [Ref. 82: p. 32]:

- The ability to combine a variety of data sources through a data capture and extraction process
- The ability to add and delete data sources quickly and easily
- The ability to portray logical data structures in user terms so that the user understands what is available and can specify needed additions and deletions
- The ability to handle personal and unofficial data so that the user can experiment with alternatives based on personal judgement
- The ability to manage this wide variety of data with a full range of data management functions

When the user of a DSS invokes the dialog to gain access to the data base, it is the Database Management System (DBMS) which actually translates the request and accesses the data base to create, maintain, update, or display data as instructed. In some DSS designs it may be possible to share the DBMS which serves the central corporate information system. Usually, however, it is wise to incorporate in the DSS a separate DBMS for faster response time and more flexible data retrieval functions.

Conversely, it is seldom recommended that the DSS design should attempt to create an entirely separate data base of its own. Instead it should take advantage of the involved and time-consuming efforts already invested in the corporate data base. This can be accomplished by referencing the corporate data base whenever data is needed or by

periodically extracting needed elements into a smaller and separate DSS data base. Reliance on the corporate data base for internally-generated data needs results in decreased costs, more consistent and reliable information, simplified DSS design and development and fewer security problems [Ref. 82: p. 223].

Data resident in the data base can be organized in a number of ways. Generally, a DBMS is designed specifically for the one particular organization of data within the data base. Thus, the selection of the DBMS for a DSS depends on the data model used in the corresponding data base, which, as described above, is probably already functioning within the organization.

The various data models are described briefly below:

- Record Model: Data is organized by records which are composed of related fields. Usually each record has one or more key fields which permit sorting of the data by attributes recorded in that field. For example, each customer's record identifies all loan accounts corresponding to that customer.

- Relational Model: Data is organized in records and fields, where records are grouped by relation. For example, all car loan accounts are grouped separately from all signature loan accounts.

- Hierarchical Model: Data is organized as in the relational model but the various groups are stratified, with upper-level groups having access to relational groups at lower levels. For example, the upper-level group of all loan accounts by number can access the lower-level groups of associated customers by loan account number. This model creates data redundancy and can be difficult to alter or update, but provides other offsetting benefits such as faster access and less need for the user to understand the data organization.

- Network Model: Much like the hierarchical model except that data redundancy is eliminated or reduced by the use of logical versus actual records. Pointers are used to direct search procedures to the actual location of desired records instead of duplicating them wherever they are related to a group.

- Rule Model: Often called 'knowledge-based' systems, these models organize data and information in the form of rules or conditions. For example, when asked to compute a credit rating, the DBMS for a rule model would determine the necessary data input based on its rules for such a computation, would access or request input of such data, and would follow a predetermined set of "if - then" production rules to examine assets, liabilities, etc. in order to determine loan elligibility. This type of model is gaining increased recognition as it can support the speed and self-updating requirements of Artificial Intelligence [Ref. 88: p. 560].

Another criteria for selecting a DBMS for a DSS is the required number and variety of data operations and integrity constraints. Data operations include such capabilities as:

dictionary	views
creation	protection
deletion	sharing
update	recovery
query	file optimization

Several other DBMS choice criteria are listed and briefly explained below. It is important to remember that the more capable the DBMS, the more overhead will be involved in processing time and in development costs. The need for these capabilities must be weighed against both the overall development costs and the differences in processing or response time to the user.

- Support for Memory: Workspaces for intermediate results; libraries for saving workspaces; links or indices; triggers to remind decision makers of needed data or operations

- Data Reduction: Abstraction from large amounts of data through subsetting, combination, or aggregation

- Detail Focus: To permit managers to focus on necessary level of detail

- Multiple Source: Ability to access various internal and external data sources

- Catalogue of Sources: To identify for the manager's intelligence-gathering phase of decision-making, all available sources of relevant information

- Wide Time Frame: To permit analysis of both historical data and projections of current data into the future

- Private Data Bases: At least part of the DSS data base should be accessible only by the user

- Varying Degrees of Accuracy: At times the manager may need precision; other times he may prefer to "satisfice" and use estimates in order to save time on less critical decisions. Should provide indication of degree of accuracy of data supplied user

- Random Access: Fast access to desired data. Serial access probably too slow and frustrating for managers

- Transparency to the User: Users generally not skilled or interested in programming languages. User should be free of need to know details of data storage

3. The Model Subsystem

While decision-making models have been developed for many years, managers seldom became adept or interested in their use and have relied instead on their own heuristic methods of problem-solving. The integration of appropriate models, data, and a method of communication and flexible manipulation among models and data as permitted by a DSS

provides managers with the flexibility and and ease of manipulation which was not available with the independent models. Thus, managers provided with DSS's are much more likely to develop an appreciation for the "what-if" analysis capabilities of models or simulation [Ref. 82: p. 258].

The modeling component of a DSS is the primary tool for supporting the design and choice phases of decision-making. These phases include such activities as [Ref. 82: p. 260]:

*projection
*analysis
*comparison
*simulation
*deduction
*creation of alternatives
*optimization

In general, support for these activities depends on feedback and interaction between the decision-maker and the modeling component. The DSS should allow the examination of intermediate results, the accommodation of subjective judgement, and modification of input or model choice as the problem, or the user's perception of the problem, changes. Other key capabilities required of a DSS's modeling component include [Ref. 82: p. 33]:

- The ability to create new models quickly and easily

- The ability to access and integrate model building blocks"

- The ability to catalogue and maintain a wide range of models to support all levels of users

- The ability to interrelate these models with appropriate linkages through the data base

- The ability to manage the model base with management functions analogous to data base management (e.g., mechanisms for storing, cataloging, linking, and accessing models)

Barbosa and Herko identify several other important requirements of a DSS modeling component [Ref. 89: pp. 1-12]:

a. Interface

The user should be able to work in the problem-solving environment without unnecessary distractions. The user should not have to interrupt this process and laboriously supply some control parameters before continuing.

The control parameters should be expressed in terms with which the user will be familiar. He or she should be able to think about only those parameters that have a direct bearing on the problem-solving process.

b. Control

The user should be given a spectrum of control. If possible, the system should support manual operation as well as fully automatic operation. This permits the user to select the level of algorithmic operation that seems most suitable. It also enables the user to learn more easily by allowing him or her to proceed as slowly as desired.

The control mechanism should allow the user to introduce subjective information as demanded by the problem solution process. It should not require the user to specify all constraints a priori. This direct human control of the

solution process can make up for deficiencies in the algorithm and will often permit the system to contain a simpler algorithm, frequently resulting in smaller information burden on the user.

c. Flexibility

The algorithmic and manual operations should be interchangeable in the sense that the user can develop part of a solution via manual methods and then continue with the algorithm, or vice versa. This statement implies that the range of all operations can be cascaded in an arbitrary way. Both flexibility and control allow the user to construct a solution process that best suits the problem. This idea of interchangeability of operations is deceptively simple, but it has far-reaching implications. This is the manner by which flexibility and control are achieved. Thus a creative solution process can be composed of a sequence of subprocesses.

d. Feedback

The system should provide sufficient feedback so that the user is fully cognizant of the state of the solution generation process at all times. This feedback is essential for supporting human control of the process.

The design process itself should make use of feedback. Valuable information can be derived from introduction of the initial system or prototype to the users.

Their feedback should be especially meaningful in the area of usability.

The modeling component will be comprised of a model base, or library, and a software system to manage the models in the library. This management software is known as the Model Base Management System (MBMS). It also serves to interact with both the DBMS and the DGMS of the data base and dialog components, respectively.

The model base will contain both canned and user-built, ad-hoc models designed to support a variety of tasks at any or all of the three levels of managerial activity. Smaller models may be used as building blocks for creating larger ones.

The MBMS will handle the storage, retrieval, manipulation, creation and operation of the models in the model base. It will interact with the dialog component to permit the user to accomplish interactive modeling which permits interruption, sequence variation, and parameter changes. It will interact with the data component of the DSS to access input data, to update data based on results, to accept updates necessitated by changes in the data base, and to store intermediate results [Ref. 82: p. 263].

F. SUMMARY

DSS imply the integration and management of data, models and an interactive dialog to extend a user's judgement by permitting analyses of data. DSS are not replacements for, but rather, aids to the human decision-making processes. Each application will involve the tailoring of the user's data requirements to a specific decision-making context. Choices of database management design, dialog styles and supporting models are therefore highly context-dependent. The goals of applicability, flexibility and ease of use are common to all DSS. The degree to which these goals are realized in the design and integration of the basic components will largely determine the success or failure of the system.

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